Appendix C

ICDF Groundwater Monitoring Data Quality Objectives

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C-1. INTRODUCTION

The Waste Area Group 3, Operable Unit 3-13 Record of Decision (ROD) includes requirements for the construction and operation of the INEEL CERCLA Disposal Facility (ICDF) as a component of the remediation of contaminated soils (Group 3) at the Idaho Nuclear Technology and Engineering Center (INTEC). As a part of the WAG 3 remedial action set forth in the OU 3-13 ROD, the ICDF Complex is subject to the general remedial action objectives (RAOs) established in the OU 3-13 ROD as well as facility-specific applicable or relevant and appropriate requirements (ARARs) which include requirements for groundwater monitoring beneath the ICDF.

The OU 3-13 ROD establishes RAOs for the Snake River Plain Aquifer (SRPA) that include ensuring that in 2095 and beyond, SRPA groundwater does not exceed a cumulative carcinogenic risk of 1×10^{-4}; a total noncarcinogenic health index of 1; or applicable federal groundwater quality standards (i.e., maximum contaminant levels). The facility-specific ARARs for construction and operation of the ICDF include groundwater monitoring requirements per 40 CFR 264.92, 40 CFR 264.93, 40 CFR 264.95, 40 CFR 264.97, and 40 CFR 264.98, which discuss the groundwater protection standard, hazardous constituents, point of compliance, general groundwater monitoring requirements, and detection monitoring programs.

A groundwater monitoring program that includes both the SRPA and the vadose zone directly beneath the landfill is proposed for the ICDF. Monitoring is proposed to include both upgradient and downgradient monitoring wells in the SRPA as well as vadose zone monitoring in the unconsolidated alluvium beneath the ICDF landfill to be a key component of the monitoring program. The objective of including the additional vadose zone monitoring is to provide for the earliest possible detection of a potential release of contaminants from the ICDF landfill in the unsaturated zone **before** it can impact the SRPA.

The additional unsaturated zone monitoring is recommended for two reasons. First, significant contamination from previous activities at INTEC already exists in the SRPA beneath and downgradient of INTEC and the ICDF. The contamination present at INTEC shares the same waste constituents as the waste that will be deposited in the ICDF. Should a release occur from ICDF (or any other INTEC facility) identification the source of the release, based on saturated zone monitoring beneath ICDF would be difficult at best. This is particularly true in the critical early period of a release where concentrations are relatively low and are likely to be obscured by existing contamination. In addition, the site geology at the ICDF Complex is comprised of approximately 450 feet of intercalated sedimentary interbeds and basalt above the uppermost aquifer, the SRPA. Given the thickness of the vadose zone at this site and based on contaminant transport modeling, it will require hundreds and for some constituents, thousands of years for contaminants to reach the SRPA. Long before the release could be detected through monitoring of the upper aquifer system, a very thick vadose zone would be impacted by the release, dramatically complicating corrective actions.

The monitoring of perched water zones in the vadose zone above the SRPA is not recommended in this plan for several reasons. A remedial action is currently underway in the perched water under the OU 3-13 ROD with the objective of removing recharge sources and drying up the perched water bodies. With a predicted drain out of approximately 12 to 14 years, the perched water bodies currently beneath ICDF will have essentially drained out prior to the end of the operational period of the landfills. In addition, given the contamination already present in the perched water, a similar problem as in the SRPA occurs with first arrival and source identification. However the monitoring in the perched water with the objective of source term identification is further complicated by the difficulty in determining flow directions in the perched water system and the potential for dramatic changes in the flow direction over time. Finally, inclusion of vadose zone monitoring directly beneath landfill liner makes perched water monitoring redundant and given its limited value and difficulty of interpretation at this time it is not recommended.

Given the site-specific conditions at the location of the new ICDF Complex, a combination of SRPA and vadose zone monitoring is recommended. Through the inclusion of additional vadose zone monitoring beyond requirements called out by the ARARs, this approach will provide for the earliest possible detection of a release from the landfills before impacting the SRPA. The following text presents the data quality objectives (DQO) for the ICDF groundwater monitoring plan. These DQOs will be used as the basis for a stand-alone groundwater monitoring plan to be prepared to meet ICDF groundwater monitoring requirements.

C-2. STATE THE PROBLEM

Groundwater monitoring is required to determine if waste disposal operations at the ICDF landfill have resulted in the release of contaminants into the subsurface environment beneath the facility, potentially impacting the underlying SRPA.

C-3. IDENTIFY THE DECISION

C-3.1.1 Principal Study Questions

Has operation of the ICDF landfill resulted in the release of contaminants into the environment beneath the landfill that could exceed RAOs in the SRPA?

C-3.1.2 Alternative Actions

The alternative actions associated with this monitoring program include determining that a release of contaminants has not occurred to the environment beneath the ICDF or determining that a release has occurred and corrective actions are required.

C-3.1.3 Decision Statements

SRPA and vadose zone monitoring beneath the ICDF will be evaluated to determine whether or not ICDF waste disposal operations have resulted in a release of contaminants to the environment beneath the landfill that exceed RAOs in the SRPA. Should a release from the ICDF landfill be identified through this monitoring program, corrective actions will be evaluated and implemented.

C-4. IDENTIFY INPUTS TO THE DECISION

The inputs to the principal study question are

1. Collection and analysis of groundwater samples from the unconsolidated sediments beneath the compacted clay layer (lower-most layer) of the ICDF landfill.

2. Measurement of groundwater elevations annually in the vicinity of ICDF to determine the hydraulic gradient of the SRPA beneath ICDF.

3. Analysis of groundwater samples from the SRPA (uppermost aquifer) beneath ICDF from monitoring wells upgradient of ICDF that represent background water quality, and downgradient of the ICDF representing water quality passing the point of compliance.

4. Analyze the groundwater sampling results for each hazardous constituent comparing upgradient monitoring point concentrations to concentrations at compliance point monitoring wells to identify statistically significant evidence of contamination from the ICDF landfill in the SRPA. This evaluation will be performed in conjunction with the OU 3-13 Group 5 monitoring program and include evaluation of other contaminant and data sources.

C-5. DEFINE THE STUDY BOUNDARIES

Groundwater monitoring will monitor both the unsaturated zone and uppermost aquifer (SRPA) beneath the ICDF complex. In the unsaturated zone, the study will focus on the area immediately beneath the ICDF landfill lower-most liner. At the ICDF landfill site, the site geology of the uppermost sediments consists of approximately 35 to 50 feet of unconsolidated sand and gravels overlying basalt bedrock. This monitoring plan will focus on monitoring for leachate releases between the bottom of the landfill liner system and the top of basalt bedrock within the footprint of the landfill.

The SRPA monitoring beneath the ICDF will be conducted at points both upgradient and downgradient of the ICDF boundary. As established in the ICDF ARARs, the ICDF groundwater monitoring program is required to monitor the upper-most aquifer upgradient of the ICDF to determine the background concentrations in groundwater of hazardous constituents. The groundwater monitoring program is also required to collect groundwater samples representative of the quality of groundwater passing the point of compliance downgradient of the ICDF. The point of compliance for the ICDF groundwater monitoring program is defined as USGS-57 which is immediately downgradient of the landfill.

The groundwater monitoring program will continue at a minimum throughout the active life of the ICDF and through the ICDF closure period. The active life of the ICDF is estimated to continue for 15 years from start-up in 2003 through 2018. The closure period for the ICDF is estimated to continue 30 years past discontinuation of waste disposal at ICDF, or 2048.

C-6. DEVELOP A DECISION RULE

If it is determined through groundwater monitoring actions and data analysis that there is release of contaminants to the subsurface from ICDF, this will be reported to the Agencies and corrective actions evaluated.

In making the determination that a release has occurred, the data from vadose zone and aquifer monitoring will be weighted differently based on the level of confidence in the data. As described above, significant difficulties in the interpretation of the SRPA monitoring results are predicted given the site-specific conditions. The level of confidence in this data as an indicator of a release from the ICDF landfill is considered low in comparison to the proposed vadose zone monitoring. Therefore, the determination that a release from the ICDF will not be made solely on SRPA monitoring data alone, and must be confirmed by the vadose zone monitoring data.

C-7. SPECIFY THE TOLERABLE LIMITS ON DECISION ERRORS

Evaluation of the ICDF SRPA monitoring trend data and related decision errors will be performed as described in 40 CFR 264.97. Several methods of statistical analysis are allowed with selection of an appropriate method based on the distribution of chemical data obtained by the sampling program.

Monitoring for contaminants in the vadose zone beneath the ICDF Complex will not be amenable to the standard method of statistical comparison of a down-gradient well to the representative up-gradient well, typical of a standard RCRA groundwater monitoring program. For the ICDF monitoring program, contaminants in the vadose zone beneath the landfill will be initially determined based upon initial sampling of the vadose zone following construction of the landfill and prior to initial disposal of waste into the landfill. (Dewatering of the clay liner is predicted to occur as a result of compaction and may cause moisture migration into the vadose zone monitoring system). If water in the vadose zone is not available prior to landfill operation, it will be monitored on a periodic basis and water quality trends established.

C-8. OPTIMIZE THE DESIGN

An evaluation of vadose zone monitoring techniques suitable for monitoring beneath the ICDF landfill was conducted to identify an optimum approach given the objective for identifying the release of contaminants to the environment. With the limits of existing technologies, identifying a release of contaminants to the environment requires the collection of pore water samples for analysis of those samples. Current technologies for the collection of pore fluids from the unsaturated zone are limited to two options, porous suction cup samplers (suction lysimeters) or liner/barrier systems to intercept and collect fluids migrating vertically. In comparison of the two technologies, the overriding technical advantage of installing a liner system for the collection of potential leachate releases from the landfill is the areal extent the liner system is capable of integrating for sample collection. In the case of suction lysimeters, the sampling radius of the instrument is limited to the area surrounding the porous cup. Using a liner system, the areal extent of sampling is dramatically increased to basically the area of the liner installed. For this reason, a liner system for the interception and collection of leachate releases from the landfill is recommended. A detailed description of the proposed monitoring approach is presented in Attachment 1, "INEEL CERCLA Disposal Facility at Waste Area Group 3, Operable Unit 3-13, Vadose Zone Monitoring Plan".

Four SRPA wells will be monitored in the vicinity of the ICDF. The wells are USGS-42, USGS-57, USGS-112, and USGS-113. Monitoring well USGS-42 is located upgradient of the location of the ICDF and will provide information on background concentrations of hazardous constituents. Monitoring wells USGS-57, USGS-112, and USGS-113 are located downgradient of the ICDF and will provide data on the concentration of hazardous constituents passing the point of compliance downgradient of the facility. The selected wells are shown on Figure C-1.

The selected monitoring wells will be sampled on the same frequency as the Group 5 monitoring program. Samples collected for the ICDF monitoring program will be analyzed for WAG 3 contaminants of concern. The list of analytes may be modified over time based upon the results of leachate collection system and vadose zone monitoring system sampling results. Water elevation measurements will be collected during each sampling event. Sampling schedule and analytes are summarized below:

Years 1–6	Annual	pH (field), specific conductance (field), gross alpha/beta, tritium, I-129, T-99, Sr-90, plutonium isotopes (Pu-238, -239, -240, -241), uranium isotopes (U-234, -235, -238), Am-241, Np-237, Cs-137, mercury
Years 7–15	Biannual	Review and adjust as required
Years 16–45	Once every 5 years	Review and adjust as required

The presence of a very thick unsaturated zone above the SRPA factors significantly into the selection of monitoring wells and frequency for the ICDF SRPA monitoring. The depth to groundwater beneath the ICDF is approximately 450 ft with a heterogeneous unsaturated zone comprised of intercalated sedimentary interbeds and basalts. This causes the potential for significant lateral movement of contaminants in the vadose prior to entering the SRPA. USGS-42 is selected as the upgradient monitoring well and is believed to be sufficiently upgradient of the ICDF not to be affected by ICDF. Monitoring wells USGS-57, USGS-112, and USGS-113 were selected downgradient of the ICDF again due to the thickness of the unsaturated zone. USGS-57 is located on the immediate downgradient side of the ICDF; however given the thick vadose zone, it may not intersect contaminants migrating from the ICDF. For that reason, wells USGS-112 and USGS-113 are also selected because, given the likely dispersion of contaminants entering the aquifer, USGS-112 and USGS-113 should be capable of detecting contaminants entering the SRPA from ICDF.

The frequency of monitoring is also affected by the thickness of the vadose zone and its impact on contaminant transport. Modeling conducted in evaluation of the ICDF construction requirements indicates that the migration of even contaminants with very low distribution coefficients (K_d) is very slow. Modeling of iodine-129, which has a clay K_d of only 1 and basalt K_d of 0, produced results that indicate peak concentrations requiring over 2000 years to occur. For this reason, the frequency of sampling for established for Group 5 is considered sufficient for the ICDF groundwater sampling program.

Attachment 1

Vadose Zone Monitoring Plan

Attachment 1

Vadose Zone Monitoring Plan

1. INTRODUCTION

This attachment presents a vadose zone monitoring plan for the ICDF landfill for use as part of an alternative groundwater monitoring system proposed beneath the ICDF. The primary purpose of the vadose zone monitoring system would be to assist in the determination of whether a leak of the primary and secondary liner system of the ICDF has occurred in the areas of greatest leachate accumulation. The system would be used in conjunction with existing groundwater monitoring wells in the area to verify protection requirements of the ICDF.

Relevant technologies are addressed in the plan and the most appropriate technology is proposed for the final vadose zone monitoring system. The proposed installation consists of a tertiary leak detection system (LDS) beneath the secondary compacted clay layer (CCL). A background sampling program would be used to establish baseline concentrations of contaminants of concern (COC). In the event that COC concentrations exceeded the baseline concentrations in soil pore water from the LDS, an investigation would be conducted to determine the source of the COCs and to propose corrective action.

2. BACKGROUND

The ICDF landfill under design will accept contaminated soils from the Idaho National Engineering and Environmental Laboratory facility (INEEL). Waste soils planned for placement within this landfill are contaminated with a variety of substances, including metals and radionuclides. As part of the overall landfill monitoring program, a vadose zone monitoring program is being considered to provide early detection of any potential problems with contaminant migration out of the landfill and into the surrounding subsurface environment. The evaluation of a vadose zone monitoring system was requested by the Environmental Protection Agency (EPA) Region 10 and Idaho Department of Environmental Quality (IDEQ) as part of their review of the 30% Remedial Design/Remedial Action (RD/RA) Design Submittal for the ICDF.

The purpose of the vadose zone monitoring plan is to provide a system for quickly identifying any potential leaks from the ICDF landfill in the areas of greatest leachate accumulation. This vadose zone monitoring system is intended to supplement the deeper groundwater monitoring program that exists for this area of the INEEL. This section identifies several approaches that could potentially be used to monitor the vadose zone beneath the ICDF landfill, and evaluates the relative merits of each approach. A recommended approach to monitoring the vadose zone is developed in this section.

3. SITE GEOLOGY AND SOIL PROPERTIES

The site geology is described in detail in the ICDF Geotechnical Report (DOE 2000). In general, the near-surface geology beneath the landfill can be characterized by predominantly alluvial-deposited sand and gravel to a depth of 32 to 43 ft. Underlying the high-energy deposits of sand and gravel is a low-energy "old alluvium" deposit of clay, which ranges in depth from 2 to 7 ft and mantles consolidated basalt bedrock. Significant perched saturated lenses have been identified at 110 to 150 ft below ground surface (bgs), with the major water-bearing saturated zone beginning approximately 450 ft bgs.

The primary point sources of groundwater recharge in the area are the Big Lost River and the INEEL percolation ponds. The percolation ponds are located east of the landfill and receive approximately 1.5 million gallons per day of treated water. Groundwater has been noted to perch at interbedding layers and at the bedrock surface in the vadose zone and is expected to flow horizontally for significant distances away from these recharge points. Notably, current construction at INEEL is relocating the percolation ponds several miles to the west of the ICDF Complex.

Unsaturated soil flow parameters, including water retention characteristics and the unsaturated hydraulic conductivity function, are important to understand for the appropriate design of vadose zone monitoring systems. Since the old alluvium is the stratigraphic unit most likely to be monitored for soil pore water quality (as it is the uppermost unit beneath the ICDF landfill that could perch infiltration), soil properties from this unit were investigated. The saturated hydraulic conductivity and water retention points were taken from the ICDF Geotechnical Report (DOE 2000) and water retention and unsaturated hydraulic conductivity functions were fitted to the data (Appendices A and B) with the Retention Curve Fitting Program (RETC) (Van Genuchten et al. 1991). The RETC program is used to fit non-linear hydraulic functions to laboratory or field-measured water retention and hydraulic conductivity data. These hydraulic functions make it possible to draw conclusions about water status and movement in the vadose zone under a wide range of moisture conditions.

4. POTENTIAL VADOSE ZONE MONITORING APPROACHES

As part of the overall landfill environmental monitoring program, a vadose zone monitoring program is being considered to provide quick detection of leaks from the bottom liner. Because the monitoring program may operate for decades into the future, it is important that the selected monitoring approaches are robust and remain viable for long periods of time. An appropriate vadose zone monitoring program should also provide data that can be used to conclusively identify the source of any detected problems. This section briefly outlines three vadose zone monitoring methodologies that are applicable to the subject landfill. More detailed descriptions of the methodologies described here can be found in Wilson et al. (1995) and Stephens (1996).

Three primary approaches can be used to detect leaks from a landfill. These include the tracking of soil moisture, the direct measurement of landfill leakage, and the monitoring of soil pore water quality.

4.1 Soil Moisture Monitoring

Soil moisture monitoring encompasses the monitoring of actual soil water content or soil water pressure. The soil moisture monitoring approach to landfill leak detection in the vadose zone relies on the tracking of changes in soil moisture throughout the soil profile beneath the landfill. Significant changes in soil moisture, caused by soil water flux into or out of a specific depth range being monitored, can indicate leaks through the landfill liner. These changes can also be associated with outside influences such as groundwater recharge from the surrounding area around the landfill. Without the knowledge of soil pore water quality, it is difficult to discern the source of the water. A significant increase in soil moisture would typically trigger a more extensive investigation to determine the source of the increased moisture.

Soil water content and soil water pressure are related by a hysteretic non-linear function, so estimation of one field-measured parameter from the other can be subject to large error. Instruments available to monitor soil water pressure include tensiometers, granular matrix resistance sensors, heat dissipation sensors, and psychrometers. However, most of these sensors are not well suited to deep, long-term installations. While there are some experimental tensiometers designed for deep installations, these instruments have not been widely tested.

The most appropriate soil moisture monitoring technologies for long-term monitoring beneath a landfill are the time domain reflectometry (TDR) method and neutron scattering method. Both methods evaluate in situ volumetric soil water content and, with soil-specific calibrations, both methods can estimate soil water content to within 2 percent volumetric water content. The TDR method is based on estimating the dielectric properties of the soil media surrounding a buried waveguide using a high-resolution oscilloscope. Because the dielectric constant of water is significantly higher than that of air and soil minerals, the bulk dielectric permittivity of the soil media can be closely correlated to the volumetric soil water content.

The neutron scattering method uses fast neutrons emitted from a radioactive source of americium and beryllium or californium and measures the return rate of thermalized neutrons. Fast neutrons are thermalized or slowed most effectively by collisions with hydrogen atoms. In most soils, the predominant source of hydrogen is water and consequently, the return rate of thermalized neutrons can be closely correlated to the volumetric soil water content. Although the radioactive sources are sealed and do not impart radioactive contamination into the subsurface, there is potential for radionuclide interference with neutron probe readings in highly contaminated materials. Typical source strengths used in neutron probes are on the order of 60-100μCi for californium-252 and 10-100μCi for americium-241:beryllium-9. To ensure that background neutron interference is not a problem, the source strengths would have to be compared to the expected radionuclide concentrations in the surrounding soil.

The primary difference in installation and measurement between the two methods is that neutron scattering is a borehole method, while TDR is usually applied with several permanently installed sensors buried in the soil profile with sensor leads routed to the surface. Although there are installations of TDR probes that have been continuously monitored without a problem for up to 10 years, how long these sensors can be expected to function beyond that time frame is unknown. With borehole neutron moisture meter installations, the only in-ground equipment is an aluminum or steel borehole conduit used for periodic access with the meter. Since no meter components are permanently installed in the borehole for the neutron scattering method, this type of system is best suited to long-term monitoring. However, it should be notedthat a neutron moisture meter must be registered with the Nuclear Regulatory Commission (NRC) and must be carefully stored with all transportation fully documented, and that all operators must be trained and be monitored for radiation exposure.

The major limitation of soil moisture monitoring methods is that increases in soil moisture in the native soil material outside of a landfill cell cannot necessarily be associated with leaks through the landfill liner. Even in soil material directly under a landfill, soil moisture can be increased by natural moisture migration from the compacted clay liner or surface recharge around the landfill that has been transported horizontally at material interfaces either as unsaturated flow or in perched conditions.

4.2 Leak Detection System

An LDS is sometimes used beneath a landfill cell or leachate reservoir to indicate when a breach in the bottom liner system has occurred. An LDS usually consists of a high-density polyethylene (HDPE) liner and geonet drain fabric placed directly beneath the bottom liner that is sloped to a central sump. The sump provides access to any liquid collected in the LDS for removal and analysis. LDSs are very expensive to implement over large areas. However, more affordable yet effective LDSs can be placed in limited aerial extent only in the regions of greatest probability of leachate collection and bottom liner leakage. The greatest probability of bottom liner leakage is usually near the leachate collection and removal system (LCRS) sump. The hydraulic head is usually the greatest over the liner near the LCRS sump and the greatest density of seams in the geomembranes usually occurs at this location. Because a LDS is usually placed directly beneath and in contact with the bottom liner of a landfill, water capture in the LDS sump will be almost exclusively from leaks through the liner system. However, when a partial

LDS is installed, there is some possibility that perched water outside of the landfill cell can seep in along the edges of the LDS. In that case, chemical analysis of any water captured in the LDS sump can be used to distinguish between leaks and outside groundwater influences. Simple conductivity tests can be used to indicate if further analysis may be required.

4.3 Soil Pore Water Sampling for Indicator Waste Constituents

Soil pore water beneath a landfill can be collected by destructive methods such as by soil core removal or by non-destructive repeatable sampling methods that use porous suction cup samplers (PSCS), pan lysimeters, or wick lysimeters. For long-term monitoring programs, non-destructive methods are the most favorable. Of the non-destructive methods, only PSCS and wick lysimeters are capable of extracting soil pore water under unsaturated soil conditions without significantly altering vadose zone flow streamlines around the sampler. With a pan lysimeter, water in the soil above the pan must accumulate until the soil reaches saturation before water will drain out of the soil and into the pan. Natural pore water constituent concentrations are not well estimated with pan lysimeters due to the natural streamline interference, and, unless the pan lysimeter is very large, edge effects can cause significant undercollection of recharge. Under the variably saturated conditions expected in the vadose zone beneath the landfill, a sampler must be able to sample under both saturated and unsaturated soil conditions and should not alter vadose zone flow streamlines or pore water quality significantly. Because wick lysimeters are only suited for relatively shallow installation at less than about 10 ft bgs, PSCS are the best instrument for variably saturated soil pore water sampling beneath landfills.

A PSCS consists of a porous cup attached to a sampling reservoir and HDPE tubing. The sampler is buried in the soil and the sampler tubing is extended to the soil surface for repeated access. (Appendix C presents a figure and details.) The area around the porous cup is typically backfilled with silica flour to ensure good hydraulic contact between the soil and the sampler. After a hydraulic continuum is established between water in the porous cup and water in the surrounding soil, a vacuum can be applied to the sampling reservoir through the sampler tubing. The applied vacuum establishes an inward pressure gradient to the sampler if antecedent soil water tension around the PSCS is less than the applied tension. When an inward pressure gradient is established, water in the soil matrix around the sampler flows into the sampling reservoir where it is stored for later removal through the sample tubing. To remove water collected in the PSCS from the sampler, pressure is applied to the vacuum/pressure line and water is forced out of the fluid return line and into a sample collection bottle.

The porous material used in a PSCS tip must be evaluated for the desired application. Several porous materials are available for PSCS tips including ceramic, stainless steel, and nylon. The primary characteristics to evaluate include chemical sorption characteristics, the air entry or bubbling pressure, and the durability of the material. While anionic inorganic chemicals can be sampled with all available porous materials with little problem, cations including metals and organic substances can be significantly sorbed by some of the porous materials. The three porous materials evaluated can be ranked in the following order for decreasing sorption of metals and organics.

Metal Sorption: Ceramic > Stainless Steel > Nylon

Organic Sorption: Nylon > Ceramic > Stainless Steel

There is little information on radionuclide sorption onto porous tip materials. However, anionic species should not experience significant sorption onto porous cup materials. Chemicals can also be leached from the porous materials in trace quantities resulting in false-positive detections. Ceramic materials have been reported to release a wide range of elements including Al, Ca, CO_3, HCO_3, Cr, Cu, K, Mg, Na, SiO_2, SO_4, and Zn. Nylon materials have been reported to release Ca, Cr, Cu, Fe, Mg, Na, and Si while stainless steel has only been reported to release Zn. Although not documented, stainless steel might also be expected to release Cr.

In terms of durability, ceramic and stainless steel PSCS have been monitored continuously without a problem at sites for over 10 years. Nylon samplers have been tested to a lesser extent. Although they show very favorable results for minimal metal sorption, the nylon membranes are more fragile than ceramic and stainless steel and could be a problem in deep installations where it would be very difficult to replace a leaking sampler.

The air entry pressure of a porous material corresponds to the pressure below which (i.e., greater tension) the largest pores drain and air is allowed to enter the material. Once air enters through a PSCS porous tip, the sampling vacuum is rapidly relieved by air entry and little or no water is collected. This vacuum should not be exceeded when sampling a PSCS. Air entry pressures range from about -0.30Bar for stainless steel up to about -1Bar for ceramic and nylon materials. Using the hydraulic properties of the old alluvium, the hydraulic conductivity of that material would be in the range of $3x10^{-10}$ cm/s to $5x10^{-11}$ cm/s under conditions where the soil water tension is greater than -0.30Bar (see Appendix A). Under these conditions, soil water movement through the old alluvium will be insignificant. Therefore, the allowable sampling pressure range of 0 to –0.30Bar does not significantly hinder the utility of PSCSs in this material.

For deep installations of PSCS (greater than about 25 ft bgs), samplers with internal check valves must be used so that water is not forced back out of the sampler when pressure is applied to retrieve the sample (see Appendix C). With a check valve PSCS, the vacuum is applied and water is drawn into a sealed chamber through the porous tip as described previously. The sealed chamber is separated from the rest of the sampler by a plug and a check valve. When the sample is retrieved, a vacuum is again applied to pull the sample through the check valve into the sampler body. A positive pressure is then applied, which forces the check valve closed and pushes the sample up through the fluid return line to the surface.

Soils beneath the percolation ponds comprise one of the largest sources of waste soils to be placed in the landfill and, consequently, contain the same contaminants that would be sampled for with the PSCSs. Because recharge from the percolation ponds has been noted to perch above the basalt bedrock surface, it is likely that there will be some background contamination in the vadose zone beneath the landfill. To distinguish future sampling results from background influences, a comprehensive background sampling of the PSCS would be required to establish baseline concentrations of the COCs.

Once an appropriate PSCS design is selected and the samplers are installed, a monitoring program must be developed to collect information on soil pore water quality. Because the range of contaminants within a landfill is usually so large, one or two indicator parameters are usually chosen that are predominant constituents of the landfill contents. The target indicator species usually include the most mobile of chemical parameters that are widespread within the waste material. Common indicator parameters include electrical conductivity, chloride, fluoride, bromide, nitrate, and iodine.

4.4 Comparison of Monitoring Approaches

Each of the considered vadose zone monitoring approaches is associated with specific benefits and limitations. To aid in the comparison of considered approaches and the final selection of one or more approaches for the proposed monitoring plan, a comparison matrix of the most appropriate approaches is presented in Table A-1.

Table 1. Vadose Zone Monitoring Approach Comparison Matrix.

Evaluation Parameter	Soil Moisture Monitoring with Neutron Scattering	Leak Detection System	Soil Pore Water Sampling with Porous Suction Cup Samplers
Longevity	Long-term	Long-term	Long-term
Maintenance	Minimal	Minimal	Minimal
Zone of Sampling Influence	Approximately 6-inch radius around access tube	Area of LDS liner – usually several hundred square feet	Approximately 6-inch radius around access tube
Unsaturated or Saturated Flow Sampling	Both	Only Saturated Flow	Both
Calibration Required?	Yes	No	No
Background Monitoring Required?	Yes	No	Yes
Number of Units Typically Required Under a Landfill	Several	One	Several
Ability to Monitor Leakage Water Quality?	No	Yes	Yes
Potential for Reaction to Conditions not Resulting from Landfill Leakage	High	Low	Moderate

5. PROPOSED VADOSE ZONE MONITORING PLAN

The proposed vadose zone monitoring plan includes the use of a tertiary LDS under the LCRS sump. Although the liner design is very conservative and already includes an integral LDS, this partial tertiary LDS would provide immediate detection of leaks through the liner system in the highest leak risk area. No soil moisture monitoring or soil pore water sampling is proposed, because the results are likely to be subject to error from outside influences such as the river and percolation pond recharge perching at the old alluvium and bedrock interfaces. An LDS was chosen over the two other approaches primarily because it is expected to provide the most robust and direct indication of any potential leakage from the ICDF landfill cells in the areas of greatest leachate accumulation.

The proposed tertiary LDS will be approximately 22 ft in width and will extend the entire length of the central drainage area in the middle and bottom of the cell. In the initial construction phase, the tertiary LDS will be built to the extent of the central drainage area in Cell 1. The LDS can be easily extended to cover the central drainage area across Cell 2 in the future. Following the slope of the bottom of the cell, the tertiary LDS will drain to a leak monitoring sump near the LDRS sump (see Appendix D, Figure D-1). A geotextile- and gravel-wrapped HDPE collection pipe will be used to collect leakage from beneath the CCL as shown in Appendix D, Figure D-2. A HDPE geomembrane will be used as the barrier layer to direct leakage into the collection system. Drain sand will be used to cover the collection system for protection of the system from the overlying CCL construction. The collection sump for this tertiary collection system will be located directly beneath the LDRS collection sump, as shown in Appendix D, Figure D-2.

The leak monitoring sump will be regularly inspected for any collected fluids. In the case of fluid capture, all fluids will be pumped out of the sump and tested for selected indicator parameters. In the case that indicator parameters are present, a full chemical analysis would be completed on the liquids. In the event that indicator parameter concentrations exceeded the baseline concentrations established in the soil pore water from the LDS, an investigation would be conducted to determine the source of the COCs and to propose corrective action. Notably, as the tertiary LDS is located directly beneath the CCL, construction pore water is expected to squeeze out of the CCL due to waste loading, and collect in the tertiary system.

Using a chemical screening of the waste soil materials to be placed in the landfill, indicator parameters would be chosen for the monitoring program. Two prevalent radionuclides in the waste soil material are iodine-129 and tritium. Both of these species are very mobile in the subsurface environment, and may also be used as indicators. Results of ongoing leachate sampling would be reviewed through the operation of the ICDF landfill and indicator parameters would be periodically reevaluated. Following installation, the tertiary LDS would be sampled regularly for the indicator parameters. In the event that indicator waste constituents were present in quantities exceeding baseline concentrations, a more detailed chemical analysis would be completed on the liquids.

The tertiary monitoring system data would be used in the objective and critical analysis of leak detection data and groundwater monitoring data obtained from the ICDF. The data would be used in conjunction with the secondary LDS data to determine:

1. That the liner systems are functioning as designed

2. Whether a leak has occurred within the ICDF

3. To what extent a leak has extended (has it left cell confinement?)

4. What the potential location and source of the leak could be, or what source of other site contamination could be impacting monitoring points

5. To what extend any remedial activities are necessary, and how effective they might be once implemented.

6. REFERENCES

DOE-ID, 2000, "Geotechnical Report for the Conceptual Design of the INEEL CERCLA Disposal Facility at Waste Area Group 3, Operable Unit 3-13 (Draft)," DOE/ID-10812, Rev. B, U.S. Dept. of Energy, Idaho Operations Office, Idaho Falls, Idaho

Stephens, D.B, 1996, *Vadose Zone Hydrology*, Lewis Publishers, Boca Raton, Florida.

Van Genuchten, M.T., F.J. Leij, and S.R. Yates, 1991, *The RETC code for quantifying the hydraulic functions of unsaturated soils*, Rep. 600/2-91/065, U.S. Environmental Protection Agency, Ada, Oklahoma.

Wilson, L.G., L.G. Everett, and S.J. Cullen, 1995, *Handbook of Vadose Zone Characterization and Monitoring*, Lewis Publishers, Boca Raton, Florida.

Appendix A

Soil Water Retention and Unsaturated Hydraulic Conductivity Charts

Appendix A

Soil Water Retention and Unsaturated Hydraulic Conductivity Charts

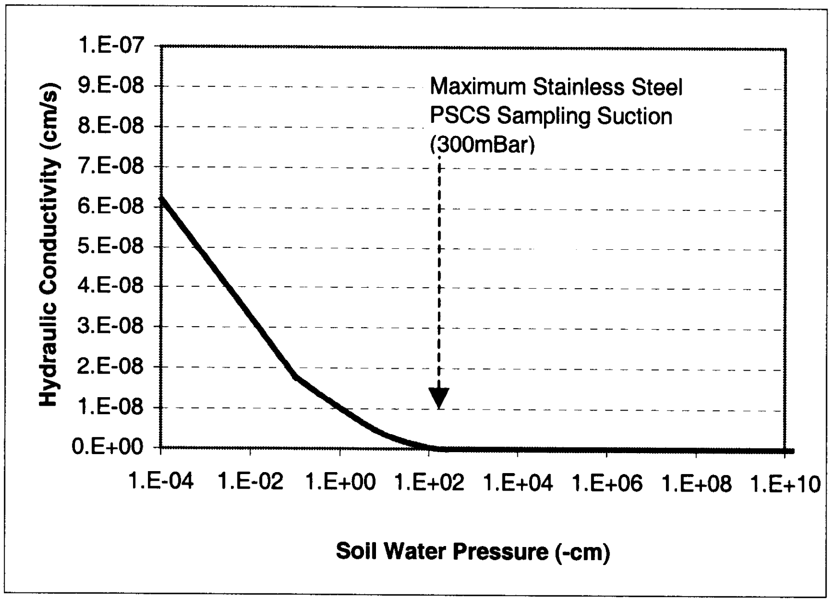

Figure C-A-1. Unsaturated hydraulic conductivity of old alluvium in Boring SPT-3.

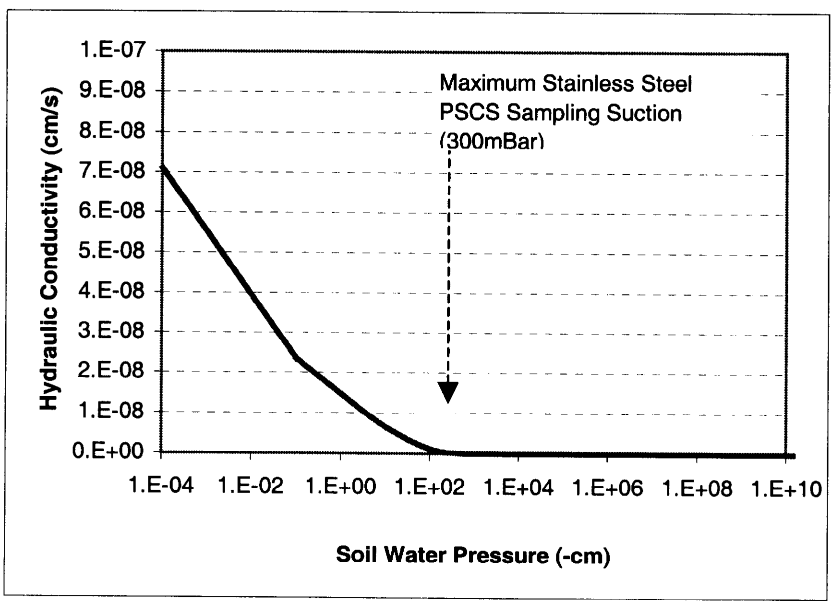

Figure C-A-2. Unsaturated hydraulic conductivity of old alluvium in Boring SPT-5.

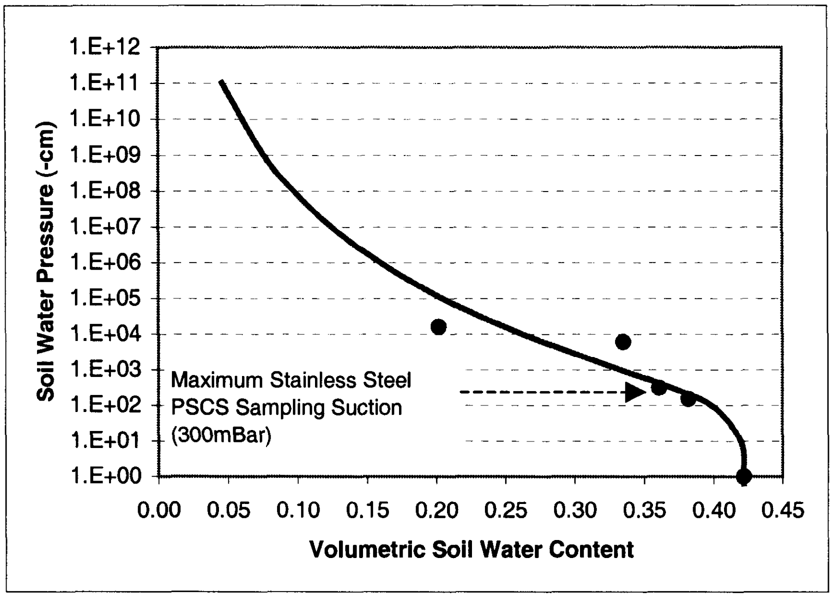

Figure C-A-3. Water retention characteristics of old alluvium in Boring SPT-3.

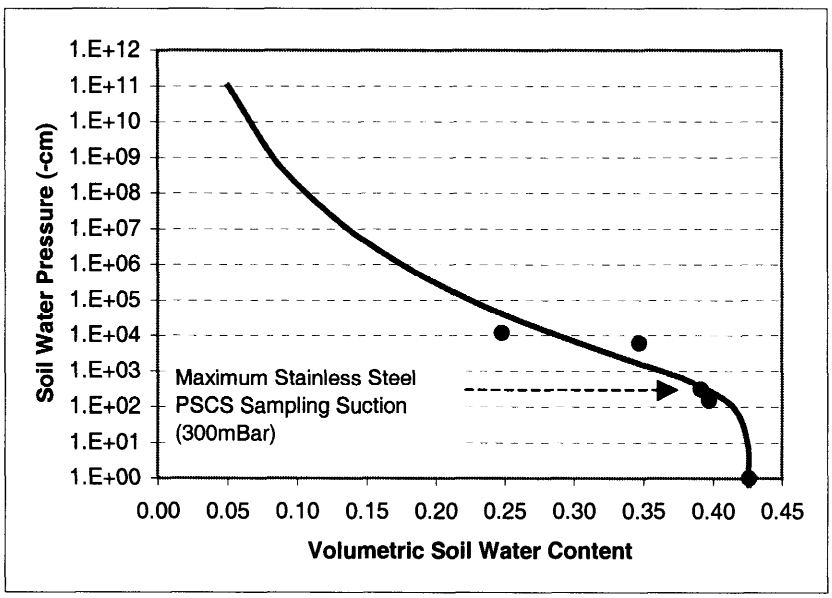

Figure C-A-4. Water retention characteristics of old alluvium in Boring SPT-5.

Appendix B

RETC Soil Hydraulic Property Model Results

Appendix B

RETC Soil Hydraulic Property Model Results

Boring SPT-3 ICPP-BOR-S-182

```
******************************************************************
*                                        *
*    ANALYSIS OF SOIL HYDRAULIC PROPERTIES               *
*                                        *
*    Welcome to RETC                             *
*                                        *
*    MUALEM-BASED RESTRICTION, M=1-1/N                   *
*    ANALYSIS OF RETENTION DATA ONLY                   *
*    MTYPE= 3    METHOD= 3                         *
*                                        *
******************************************************************
```

INITIAL VALUES OF THE COEFFICIENTS

=================================

NO	NAME	INITIAL VALUE	INDEX
1	ThetaR	.1500	1
2	ThetaS	.4220	0
3	Alpha	.0080	1
4	n	1.0900	1
5	m	.0826	0
6	l	.5000	0
7	Ks	1.0000	0

OBSERVED DATA

=============

OBS. NO.	PRESSURE HEAD	WATER CONTENT	WEIGHTING COEFFICIENT
1	.000	.4220	1.0000
2	153.000	.3820	1.0000
3	306.000	.3610	1.0000
4	6119.000	.3350	1.0000
5	16113.000	.2020	1.0000

NIT	SSQ	ThetaR	Alpha	n
0	.01693	.1500	.0080	1.0900
1	.00611	.0195	.0094	1.1201
2	.00582	.0006	.0084	1.1067
3	.00582	.0004	.0084	1.1068
4	.00582	.0002	.0084	1.1068
5	.00582	.0000	.0084	1.1068

WCR IS LESS THEN 0.001: CHANGED TO FIT WITH WCR=0.0

NIT	SSQ	Alpha	n
0	.00689	.0080	1.0900
1	.00582	.0079	1.1082
2	.00582	.0082	1.1079
3	.00582	.0082	1.1077
4	.00582	.0082	1.1077
5	.00582	.0082	1.1077
6	.00582	.0082	1.1077

CORRELATION MATRIX

==================

	Alpha	n
	1	2
1	1.0000	
2	-.8912	1.0000

RSQUARED FOR REGRESSION OF OBSERVED VS FITTED VALUES = .79224307

==

NONLINEAR LEAST-SQUARES ANALYSIS: FINAL RESULTS

===

				95% CONFIDENCE LIMITS	
VARIABLE	VALUE	S.E.COEFF.	T-VALUE	LOWER	UPPER
Alpha	.00822	.01459	.56	-.0382	.0547
n	1.10771	.05714	19.39	.9259	1.2895

OBSERVED AND FITTED DATA

=======================

NO	P	LOG-P	WC-OBS	WC-FIT	WC-DEV
1	.1000E-04	-5.0000	.4220	.4220	.0000
2	.1530E+03	2.1847	.3820	.3893	-.0073
3	.3060E+03	2.4857	.3610	.3708	-.0098
4	.6119E+04	3.7867	.3350	.2764	.0586
5	.1611E+05	4.2072	.2020	.2492	-.0472

SUM OF SQUARES OF OBSERVED VERSUS FITTED VALUES

===

	UNWEIGHTED	WEIGHTED
RETENTION DATA	.00582	.00582
COND/DIFF DATA	.00000	.00000
ALL DATA	.00582	.00582

SOIL HYDRAULIC PROPERTIES (MTYPE = 3)

====================================

WC	P	LOGP	COND	LOGK	DIF	LOGD
.0172	-.9607E+15	14.983	.5097E-31	-31.293	.2639E-13	-13.578
.0215	-.1210E+15	14.083	.5611E-29	-29.251	.2928E-12	-12.533
.0258	-.2227E+14	13.348	.2614E-27	-27.583	.2092E-11	-11.679
.0301	-.5323E+13	12.726	.6727E-26	-26.172	.1103E-10	-10.957
.0344	-.1541E+13	12.188	.1121E-24	-24.950	.4655E-10	-10.332
.0388	-.5161E+12	11.713	.1341E-23	-23.873	.1658E-09	-9.780
.0431	-.1941E+12	11.288	.1234E-22	-22.909	.5165E-09	-9.287
.0474	-.8010E+11	10.904	.9196E-22	-22.036	.1444E-08	-8.841
.0517	-.3571E+11	10.553	.5751E-21	-21.240	.3690E-08	-8.433
.0560	-.1698E+11	10.230	.3106E-20	-20.508	.8748E-08	-8.058
.0603	-.8535E+10	9.931	.1480E-19	-19.830	.1945E-07	-7.711
.0646	-.4498E+10	9.653	.6332E-19	-19.198	.4094E-07	-7.388
.0689	-.2470E+10	9.393	.2467E-18	-18.608	.8211E-07	-7.086
.0732	-.1407E+10	9.148	.8847E-18	-18.053	.1579E-06	-6.802
.0775	-.8277E+09	8.918	.2950E-17	-17.530	.2925E-06	-6.534
.0818	-.5010E+09	8.700	.9216E-17	-17.035	.5240E-06	-6.281
.0861	-.3112E+09	8.493	.2716E-16	-16.566	.9111E-06	-6.040
.0904	-.1978E+09	8.296	.7591E-16	-16.120	.1542E-05	-5.812
.0947	-.1284E+09	8.109	.2023E-15	-15.694	.2547E-05	-5.594

.0990	-.8501E+08	7.929	.5161E-15	-15.287	.4113E-05	-5.386
.1033	-.5726E+08	7.758	.1265E-14	-14.898	.6508E-05	-5.187
.1077	-.3920E+08	7.593	.2990E-14	-14.524	.1011E-04	-4.995
.1120	-.2723E+08	7.435	.6832E-14	-14.165	.1543E-04	-4.812
.1163	-.1918E+08	7.283	.1513E-13	-13.820	.2318E-04	-4.635
.1206	-.1369E+08	7.136	.3256E-13	-13.487	.3431E-04	-4.465
.1249	-.9881E+07	6.995	.6819E-13	-13.166	.5010E-04	-4.300
.1292	-.7213E+07	6.858	.1393E-12	-12.856	.7221E-04	-4.141
.1335	-.5320E+07	6.726	.2780E-12	-12.556	.1028E-03	-3.988
.1378	-.3962E+07	6.598	.5426E-12	-12.266	.1448E-03	-3.839
.1421	-.2977E+07	6.474	.1038E-11	-11.984	.2018E-03	-3.695
.1464	-.2256E+07	6.353	.1946E-11	-11.711	.2785E-03	-3.555
.1507	-.1724E+07	6.237	.3585E-11	-11.446	.3807E-03	-3.419
.1550	-.1327E+07	6.123	.6490E-11	-11.188	.5159E-03	-3.287
.1593	-.1029E+07	6.012	.1156E-10	-10.937	.6932E-03	-3.159
.1636	-.8034E+06	5.905	.2028E-10	-10.693	.9243E-03	-3.034
.1679	-.6312E+06	5.800	.3505E-10	-10.455	.1223E-02	-2.913
.1722	-.4990E+06	5.698	.5975E-10	-10.224	.1607E-02	-2.794
.1766	-.3967E+06	5.598	.1005E-09	-9.998	.2098E-02	-2.678
.1809	-.3172E+06	5.501	.1670E-09	-9.777	.2720E-02	-2.565
.1852	-.2549E+06	5.406	.2742E-09	-9.562	.3506E-02	-2.455
.1895	-.2059E+06	5.314	.4451E-09	-9.352	.4493E-02	-2.347
.1938	-.1671E+06	5.223	.7147E-09	-9.146	.5725E-02	-2.242
.1981	-.1363E+06	5.134	.1136E-08	-8.945	.7257E-02	-2.139
.2024	-.1116E+06	5.048	.1787E-08	-8.748	.9153E-02	-2.038
.2067	-.9177E+05	4.963	.2785E-08	-8.555	.1149E-01	-1.940
.2110	-.7577E+05	4.879	.4301E-08	-8.366	.1435E-01	-1.843
.2153	-.6280E+05	4.798	.6584E-08	-8.182	.1785E-01	-1.748
.2196	-.5224E+05	4.718	.9994E-08	-8.000	.2210E-01	-1.656
.2239	-.4361E+05	4.640	.1505E-07	-7.822	.2726E-01	-1.565
.2282	-.3653E+05	4.563	.2249E-07	-7.648	.3348E-01	-1.475
.2325	-.3070E+05	4.487	.3335E-07	-7.477	.4098E-01	-1.387
.2368	-.2588E+05	4.413	.4912E-07	-7.309	.4997E-01	-1.301
.2411	-.2188E+05	4.340	.7183E-07	-7.144	.6072E-01	-1.217
.2454	-.1856E+05	4.269	.1044E-06	-6.981	.7353E-01	-1.134
.2498	-.1578E+05	4.198	.1506E-06	-6.822	.8877E-01	-1.052
.2541	-.1345E+05	4.129	.2161E-06	-6.665	.1068E+00	-.971
.2584	-.1150E+05	4.061	.3082E-06	-6.511	.1282E+00	-.892
.2627	-.9852E+04	3.994	.4371E-06	-6.359	.1534E+00	-.814
.2670	-.8461E+04	3.927	.6165E-06	-6.210	.1831E+00	-.737
.2713	-.7282E+04	3.862	.8649E-06	-6.063	.2179E+00	-.662

.2756	-.6281E+04	3.798	.1207E-05	-5.918	.2587E+00	-.587
.2799	-.5428E+04	3.735	.1677E-05	-5.775	.3065E+00	-.514
.2842	-.4700E+04	3.672	.2319E-05	-5.635	.3622E+00	-.441
.2885	-.4077E+04	3.610	.3191E-05	-5.496	.4272E+00	-.369
.2928	-.3542E+04	3.549	.4374E-05	-5.359	.5029E+00	-.298
.2971	-.3082E+04	3.489	.5970E-05	-5.224	.5910E+00	-.228
.3014	-.2686E+04	3.429	.8116E-05	-5.091	.6932E+00	-.159
.3057	-.2344E+04	3.370	.1099E-04	-4.959	.8119E+00	-.090
.3100	-.2047E+04	3.311	.1484E-04	-4.829	.9496E+00	-.022
.3143	-.1790E+04	3.253	.1996E-04	-4.700	.1109E+01	.045
.3187	-.1567E+04	3.195	.2677E-04	-4.572	.1294E+01	.112
.3230	-.1373E+04	3.138	.3580E-04	-4.446	.1509E+01	.179
.3273	-.1203E+04	3.080	.4775E-04	-4.321	.1758E+01	.245
.3316	-.1054E+04	3.023	.6353E-04	-4.197	.2047E+01	.311
.3359	-.9244E+03	2.966	.8435E-04	-4.074	.2383E+01	.377
.3402	-.8103E+03	2.909	.1118E-03	-3.952	.2775E+01	.443
.3445	-.7100E+03	2.851	.1479E-03	-3.830	.3231E+01	.509
.3488	-.6216E+03	2.794	.1955E-03	-3.709	.3765E+01	.576
.3531	-.5436E+03	2.735	.2581E-03	-3.588	.4392E+01	.643
.3574	-.4747E+03	2.676	.3408E-03	-3.468	.5131E+01	.710
.3617	-.4136E+03	2.617	.4499E-03	-3.347	.6007E+01	.779
.3660	-.3594E+03	2.556	.5945E-03	-3.226	.7051E+01	.848
.3703	-.3112E+03	2.493	.7866E-03	-3.104	.8303E+01	.919
.3746	-.2682E+03	2.429	.1043E-02	-2.982	.9821E+01	.992
.3789	-.2299E+03	2.362	.1388E-02	-2.858	.1168E+02	1.067
.3832	-.1956E+03	2.291	.1855E-02	-2.732	.1398E+02	1.146
.3876	-.1648E+03	2.217	.2496E-02	-2.603	.1689E+02	1.228
.3919	-.1372E+03	2.137	.3387E-02	-2.470	.2064E+02	1.315
.3962	-.1122E+03	2.050	.4652E-02	-2.332	.2561E+02	1.408
.4005	-.8966E+02	1.953	.6495E-02	-2.187	.3242E+02	1.511
.4048	-.6914E+02	1.840	.9291E-02	-2.032	.4227E+02	1.626
.4091	-.5037E+02	1.702	.1380E-01	-1.860	.5764E+02	1.761
.4134	-.3305E+02	1.519	.2187E-01	-1.660	.8495E+02	1.929
.4177	-.1675E+02	1.224	.4000E-01	-1.398	.1487E+03	2.172
.4198	-.8723E+01	.941	.6279E-01	-1.202	.2364E+03	2.374
.4209	-.4605E+01	.663	.8924E-01	-1.049	.3496E+03	2.544
.4216	-.1998E+01	.301	.1283E+00	-.892	.5403E+03	2.733
.4220	-.2487E+00	-.604	.2369E+00	-.625	.1236E+04	3.092
.4220	-.3110E-01	-1.507	.3477E+00	-.459	.2267E+04	3.356
.4220	.0000E+00		.1000E+01	.000		

END OF PROBLEM

==============

Boring SPT-5 ICPP-VOR-S-184

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*********************************************************************
*                                        *
*    ANALYSIS OF SOIL HYDRAULIC PROPERTIES                *
*                                        *
*    Welcome to RETC                           *
*                                        *
*    MUALEM-BASED RESTRICTION, M=1-1/N                *
*    ANALYSIS OF RETENTION DATA ONLY                *
*    MTYPE= 3    METHOD= 3                  *
*                                        *
*********************************************************************
```

INITIAL VALUES OF THE COEFFICIENTS

==================================

NO	NAME	INITIAL VALUE	INDEX
1	ThetaR	.1500	1
2	ThetaS	.4260	0
3	Alpha	.0080	1
4	n	1.0900	1
5	m	.0826	0
6	l	.5000	0
7	Ks	1.0000	0

OBSERVED DATA

=============

OBS. NO.	PRESSURE HEAD	WATER CONTENT	WEIGHTING COEFFICIENT
1	.000	.4260	1.0000
2	153.000	.3970	1.0000
3	306.000	.3910	1.0000
4	6119.000	.3470	1.0000
5	11728.000	.2480	1.0000

NIT	SSQ	ThetaR	Alpha	n
0	.00746	.1500	.0080	1.0900
1	.00343	.0519	.0041	1.1148
2	.00332	.0200	.0038	1.1122
3	.00332	.0182	.0038	1.1121
4	.00332	.0167	.0038	1.1120
5	.00331	.0056	.0037	1.1092
6	.00330	.0041	.0037	1.1090
7	.00330	.0014	.0037	1.1083
8	.00330	.0001	.0036	1.1080

WCR IS LESS THEN 0.001: CHANGED TO FIT WITH WCR=0.0

NIT	SSQ	Alpha	n
0	.00352	.0080	1.0900
1	.00342	.0039	1.0984
2	.00330	.0036	1.1076
3	.00330	.0036	1.1081

4	.00330	.0036	1.1082
5	.00330	.0036	1.1082
6	.00330	.0036	1.1083
7	.00330	.0036	1.1083
8	.00330	.0036	1.1083
9	.00330	.0036	1.1083

CORRELATION MATRIX

=================

	Alpha	n
	1	2
1	1.0000	
2	-.9317	1.0000

RSQUARED FOR REGRESSION OF OBSERVED VS FITTED VALUES = .82968643

==

NONLINEAR LEAST-SQUARES ANALYSIS: FINAL RESULTS

===

				95% CONFIDENCE LIMITS	
VARIABLE	VALUE	S.E.COEFF.	T-VALUE	LOWER	UPPER
Alpha	.00359	.00636	.56	-.0167	.0238
n	1.10827	.06330	17.51	.9068	1.3097

OBSERVED AND FITTED DATA

======================

NO	P	LOG-P	WC-OBS	WC-FIT	WC-DEV
1	.1000E-04	-5.0000	.4260	.4260	.0000
2	.1530E+03	2.1847	.3970	.4090	-.0120
3	.3060E+03	2.4857	.3910	.3960	-.0050
4	.6119E+04	3.7867	.3470	.3039	.0431
5	.1173E+05	4.0692	.2480	.2837	-.0357

SUM OF SQUARES OF OBSERVED VERSUS FITTED VALUES

==

	UNWEIGHTED	WEIGHTED
RETENTION DATA	.00330	.00330
COND/DIFF DATA	.00000	.00000
ALL DATA	.00330	.00330

SOIL HYDRAULIC PROPERTIES (MTYPE = 3)

==================================

WC	P	LOGP	COND	LOGK	DIF	LOGD
.0174	-.1884E+16	15.275	.7009E-31	-31.154	.7013E-13	-13.154
.0217	-.2398E+15	14.380	.7553E-29	-29.122	.7698E-12	-12.114
.0261	-.4452E+14	13.649	.3457E-27	-27.461	.5451E-11	-11.264
.0304	-.1072E+14	13.030	.8765E-26	-26.057	.2853E-10	-10.545
.0348	-.3124E+13	12.495	.1442E-24	-24.841	.1196E-09	-9.922
.0391	-.1052E+13	12.022	.1705E-23	-23.768	.4237E-09	-9.373
.0435	-.3977E+12	11.600	.1554E-22	-22.809	.1313E-08	-8.882
.0478	-.1649E+12	11.217	.1147E-21	-21.940	.3653E-08	-8.437
.0522	-.7383E+11	10.868	.7112E-21	-21.148	.9298E-08	-8.032

.0565	-.3525E+11	10.547	.3811E-20	-20.419	.2196E-07	-7.658
.0609	-.1778E+11	10.250	.1803E-19	-19.744	.4866E-07	-7.313
.0652	-.9401E+10	9.973	.7664E-19	-19.116	.1021E-06	-6.991
.0696	-.5179E+10	9.714	.2967E-18	-18.528	.2041E-06	-6.690
.0739	-.2959E+10	9.471	.1058E-17	-17.976	.3912E-06	-6.408
.0782	-.1745E+10	9.242	.3508E-17	-17.455	.7226E-06	-6.141
.0826	-.1059E+10	9.025	.1090E-16	-16.962	.1291E-05	-5.889
.0869	-.6595E+09	8.819	.3197E-16	-16.495	.2240E-05	-5.650
.0913	-.4202E+09	8.623	.8894E-16	-16.051	.3782E-05	-5.422
.0956	-.2735E+09	8.437	.2359E-15	-15.627	.6231E-05	-5.205
.1000	-.1814E+09	8.259	.5994E-15	-15.222	.1004E-04	-4.998
.1043	-.1224E+09	8.088	.1463E-14	-14.835	.1586E-04	-4.800
.1087	-.8397E+08	7.924	.3445E-14	-14.463	.2458E-04	-4.609
.1130	-.5845E+08	7.767	.7841E-14	-14.106	.3745E-04	-4.426
.1174	-.4125E+08	7.615	.1730E-13	-13.762	.5617E-04	-4.251
.1217	-.2948E+08	7.470	.3710E-13	-13.431	.8299E-04	-4.081
.1261	-.2132E+08	7.329	.7744E-13	-13.111	.1210E-03	-3.917
.1304	-.1559E+08	7.193	.1577E-12	-12.802	.1741E-03	-3.759
.1348	-.1152E+08	7.061	.3136E-12	-12.504	.2475E-03	-3.606
.1391	-.8588E+07	6.934	.6104E-12	-12.214	.3481E-03	-3.458
.1434	-.6464E+07	6.810	.1164E-11	-11.934	.4843E-03	-3.315
.1478	-.4906E+07	6.691	.2177E-11	-11.662	.6673E-03	-3.176
.1521	-.3754E+07	6.574	.3998E-11	-11.398	.9109E-03	-3.041
.1565	-.2894E+07	6.461	.7217E-11	-11.142	.1233E-02	-2.909
.1608	-.2247E+07	6.352	.1282E-10	-10.892	.1654E-02	-2.781
.1652	-.1756E+07	6.245	.2243E-10	-10.649	.2203E-02	-2.657
.1695	-.1382E+07	6.140	.3868E-10	-10.413	.2911E-02	-2.536
.1739	-.1093E+07	6.039	.6577E-10	-10.182	.3821E-02	-2.418
.1782	-.8704E+06	5.940	.1104E-09	-9.957	.4981E-02	-2.303
.1826	-.6967E+06	5.843	.1830E-09	-9.738	.6451E-02	-2.190

.1869	-.5606E+06	5.749	.2998E-09	-9.523	.8306E-02	-2.081
.1913	-.4533E+06	5.656	.4855E-09	-9.314	.1063E-01	-1.973
.1956	-.3683E+06	5.566	.7779E-09	-9.109	.1353E-01	-1.869
.2000	-.3006E+06	5.478	.1234E-08	-8.909	.1714E-01	-1.766
.2043	-.2465E+06	5.392	.1937E-08	-8.713	.2159E-01	-1.666
.2087	-.2029E+06	5.307	.3012E-08	-8.521	.2707E-01	-1.568
.2130	-.1677E+06	5.224	.4642E-08	-8.333	.3378E-01	-1.471
.2173	-.1391E+06	5.143	.7093E-08	-8.149	.4197E-01	-1.377
.2217	-.1158E+06	5.064	.1075E-07	-7.969	.5193E-01	-1.285
.2260	-.9679E+05	4.986	.1615E-07	-7.792	.6398E-01	-1.194
.2304	-.8115E+05	4.909	.2409E-07	-7.618	.7853E-01	-1.105
.2347	-.6826E+05	4.834	.3567E-07	-7.448	.9602E-01	-1.018
.2391	-.5760E+05	4.760	.5243E-07	-7.280	.1170E+00	-.932
.2434	-.4874E+05	4.688	.7655E-07	-7.116	.1420E+00	-.848
.2478	-.4137E+05	4.617	.1110E-06	-6.955	.1719E+00	-.765
.2521	-.3520E+05	4.547	.1600E-06	-6.796	.2073E+00	-.683
.2565	-.3004E+05	4.478	.2292E-06	-6.640	.2493E+00	-.603
.2608	-.2569E+05	4.410	.3263E-06	-6.486	.2989E+00	-.524
.2652	-.2203E+05	4.343	.4620E-06	-6.335	.3574E+00	-.447
.2695	-.1894E+05	4.277	.6506E-06	-6.187	.4261E+00	-.370
.2739	-.1631E+05	4.212	.9114E-06	-6.040	.5068E+00	-.295
.2782	-.1408E+05	4.149	.1270E-05	-5.896	.6014E+00	-.221
.2826	-.1217E+05	4.085	.1762E-05	-5.754	.7118E+00	-.148
.2869	-.1055E+05	4.023	.2432E-05	-5.614	.8408E+00	-.075
.2912	-.9156E+04	3.962	.3343E-05	-5.476	.9910E+00	-.004
.2956	-.7961E+04	3.901	.4576E-05	-5.340	.1166E+01	.067
.2999	-.6932E+04	3.841	.6237E-05	-5.205	.1369E+01	.136
.3043	-.6045E+04	3.781	.8468E-05	-5.072	.1605E+01	.205
.3086	-.5278E+04	3.722	.1145E-04	-4.941	.1879E+01	.274
.3130	-.4614E+04	3.664	.1544E-04	-4.811	.2196E+01	.342

.3173	-.4037E+04	3.606	.2075E-04	-4.683	.2563E+01	.409
.3217	-.3535E+04	3.548	.2779E-04	-4.556	.2989E+01	.476
.3260	-.3098E+04	3.491	.3711E-04	-4.430	.3483E+01	.542
.3304	-.2717E+04	3.434	.4944E-04	-4.306	.4056E+01	.608
.3347	-.2383E+04	3.377	.6570E-04	-4.182	.4720E+01	.674
.3391	-.2090E+04	3.320	.8713E-04	-4.060	.5492E+01	.740
.3434	-.1833E+04	3.263	.1153E-03	-3.938	.6391E+01	.806
.3478	-.1607E+04	3.206	.1524E-03	-3.817	.7438E+01	.871
.3521	-.1408E+04	3.149	.2013E-03	-3.696	.8664E+01	.938
.3564	-.1232E+04	3.091	.2655E-03	-3.576	.1010E+02	1.004
.3608	-.1076E+04	3.032	.3501E-03	-3.456	.1180E+02	1.072
.3651	-.9379E+03	2.972	.4617E-03	-3.336	.1380E+02	1.140
.3695	-.8154E+03	2.911	.6094E-03	-3.215	.1619E+02	1.209
.3738	-.7063E+03	2.849	.8055E-03	-3.094	.1906E+02	1.280
.3782	-.6091E+03	2.785	.1067E-02	-2.972	.2254E+02	1.353
.3825	-.5223E+03	2.718	.1419E-02	-2.848	.2679E+02	1.428
.3869	-.4445E+03	2.648	.1894E-02	-2.723	.3207E+02	1.506
.3912	-.3748E+03	2.574	.2546E-02	-2.594	.3872E+02	1.588
.3956	-.3120E+03	2.494	.3452E-02	-2.462	.4729E+02	1.675
.3999	-.2554E+03	2.407	.4735E-02	-2.325	.5864E+02	1.768
.4043	-.2041E+03	2.310	.6605E-02	-2.180	.7422E+02	1.871
.4086	-.1574E+03	2.197	.9439E-02	-2.025	.9673E+02	1.986
.4130	-.1148E+03	2.060	.1400E-01	-1.854	.1318E+03	2.120
.4173	-.7532E+02	1.877	.2216E-01	-1.654	.1942E+03	2.288
.4217	-.3819E+02	1.582	.4048E-01	-1.393	.3397E+03	2.531
.4238	-.1990E+02	1.299	.6347E-01	-1.197	.5396E+03	2.732
.4249	-.1051E+02	1.022	.9014E-01	-1.045	.7979E+03	2.902
.4256	-.4562E+01	.659	.1294E+00	-.888	.1233E+04	3.091
.4260	-.5686E+00	-.245	.2387E+00	-.622	.2819E+04	3.450
.4260	-.7117E-01	-1.148	.3500E+00	-.456	.5171E+04	3.714

.4260 .0000E+00 .1000E+01 .000

END OF PROBLEM

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Appendix C

Porous Suction Cup Sampler/Suction Lysimeter Product Information From Soil Measurement Systems (Tuscon, AZ)

SOIL
MEASUREMENT
SYSTEMS

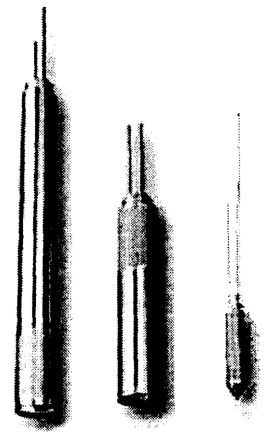
Home Company Products Ordering Support Contact Us

Column Leaching Equipment
Data Logging Interface
Flow Cell
Fraction Collector
Infiltrometer
Lysimeter
Mariotte Tube
Penetrometer
Pocket Tensimeter
Porous Membranes
Pressure Transducer
Septum Stopper
Syringe Pump
Tempe Cell
Tensimeter
Tensiometer
Vacuum Chamber
Vacuum Pump
Vacuum - Pressure Regulator

Suction Lysimeters

Description:

Suction lysimeters collect pore water from unsaturated soil. A constant vacuum source draws pore water into the lysimeter through a porous, stainless steel membrane. Pore water samples are brought to the surface by applying vacuum or pressure. Suction Lysimeters are most suitable in moist soil (tension less than 500 mbar) and can also be used below the water table.



SW-070 SW-071 SW-074

Models:

SW-070	Dual Chamber
SW-071	Single Chamber
SW-074	Small Single Camber

Click on models above for setup details.

Features:

- All welded 304 stainless steel construction
- No glue or plastics
- Suitable for organics and most inorganics
- Separate upper chamber for sample storage (model SW-070)
- One way stainless steel valve prevents back flow from storage chamber to sample chamber (model SW-070)
- Strong and durable. Suitable for installation at great depths
- 500 mbar bubbling pressure
- Optional battery powered vacuum pump (SW-073)

Specifications:

	SW-070	SW-071	SW-074
Total length (in)	18.0	10.7	4.5
Porous steel length (in)	3.7	3.7	3.7
Outside diameter (in)	2.0	2.0	.875
OD SS outlet tubing (in)	.250	.250	.125
Length SS outlets (in)	4 and 6.5	4 and 6.5	6 and 11

Directions for use of the Lysimeters

Frequently asked questions:

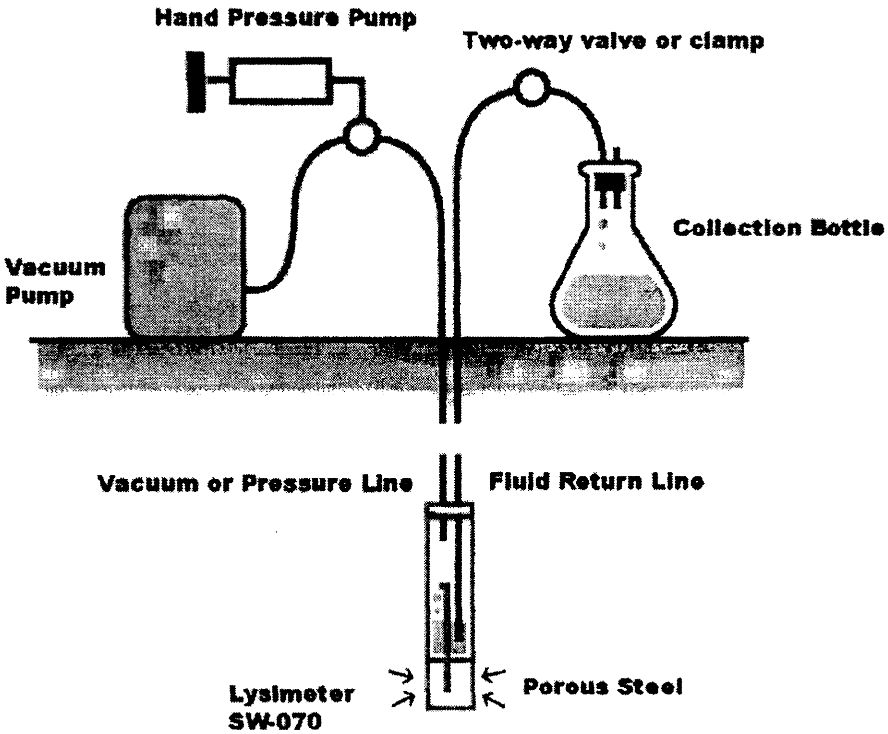
1. What is the volume of pore water that can be stored in a lysimeter?

Answer: The single chamber (2" OD) lysimeter holds 260 ml, and the dual chamber (2" OD) lysimeter holds 575 ml.

Dual Chamber (Model SW-070)

The dual chamber lysimeter is recommended for sampling unsaturated or saturated materials at depths greater than10 feet (3 m).

During sampling, vacuum is applied to the vacuum/pressure line, while keeping the fluid return line closed. For moist soil the optimum vacuum is about 300 mbar. Vacuum can be supplied with the battery powered vacuum pump from Soil Measurement Systems (Model SW-073). The partial vacuum in the lysimeter draws pore water into the lower chamber of the lysimeter through its porous stainless steel walls. From there it is drawn into the upper chamber where it is stored. The fluid is brought to the surface by applying positive pressure to the vacuum/pressure line and opening the fluid return line, forcing the fluid up to the surface and into a collection bottle. A stainless steel check valve prevents back flow of the fluid from the upper chamber into the lower chamber and the soil around the lysimeter. Sampling duration depends on the amount of sample required, the soil type, and the soil moisture content. Sampling times can vary from less than 1 hour in wet soil, to more than 1 day in drier soil.



back

Appendix D

Conceptual Vadose Zone Monitoring System Figures

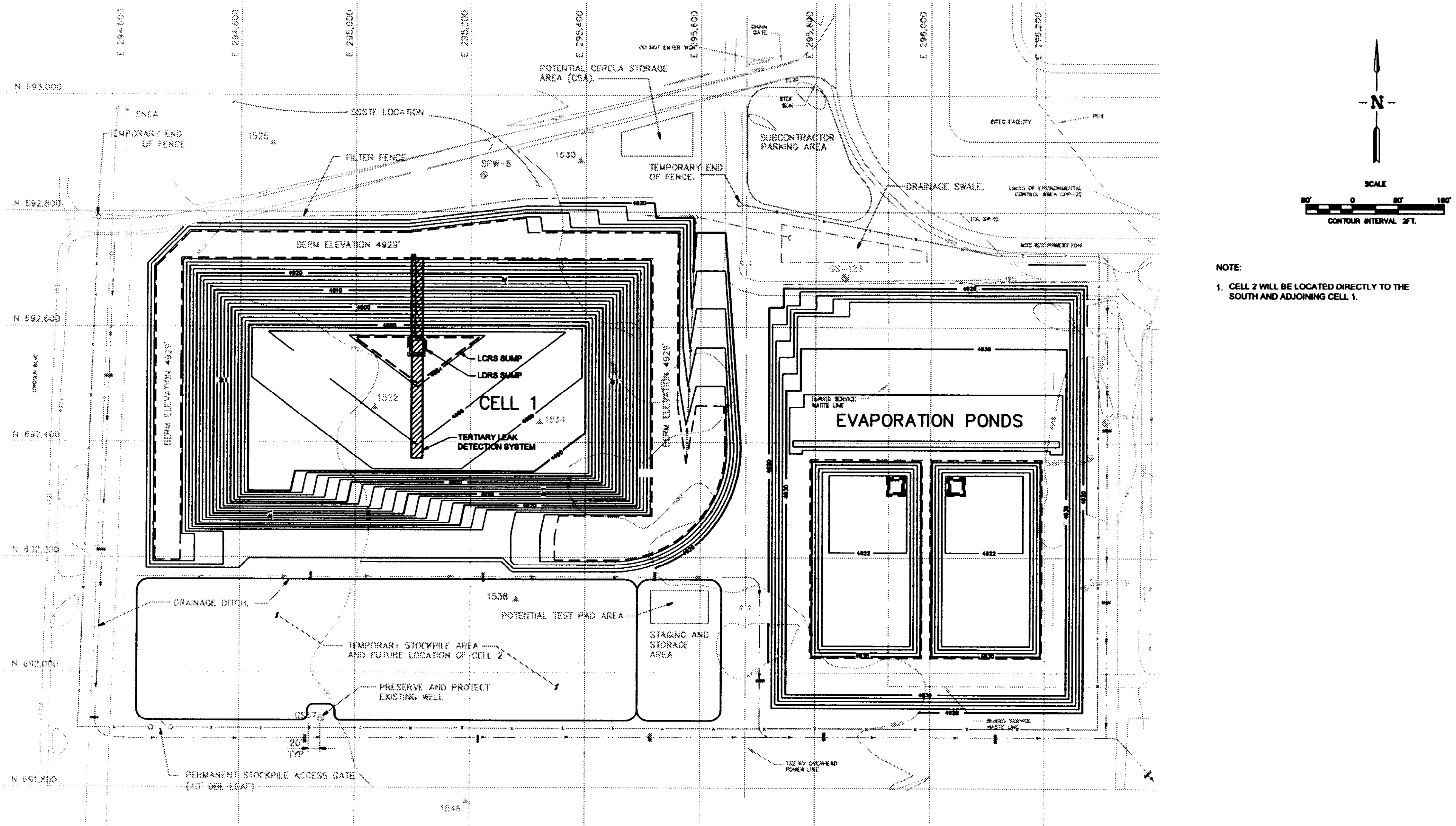


FIGURE I-1
VADOSE ZONE MONITORING PLAN

CH2MHILL

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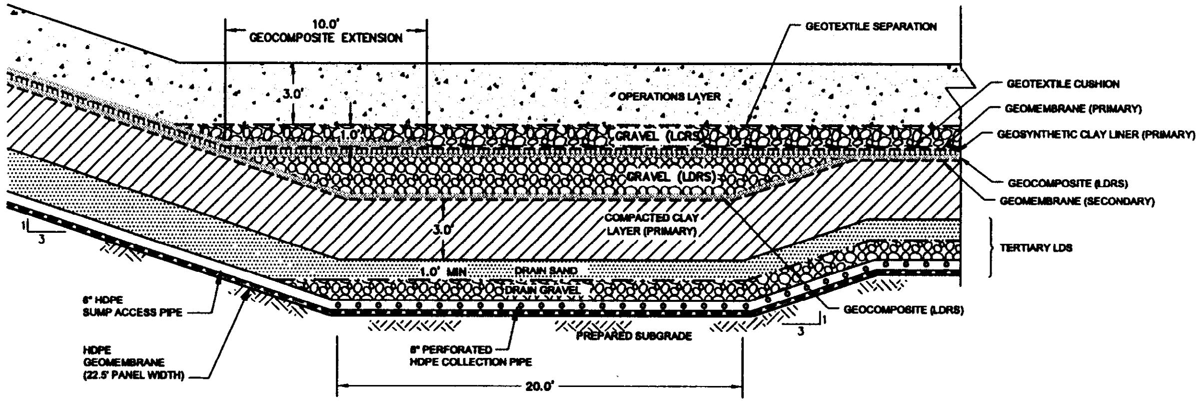
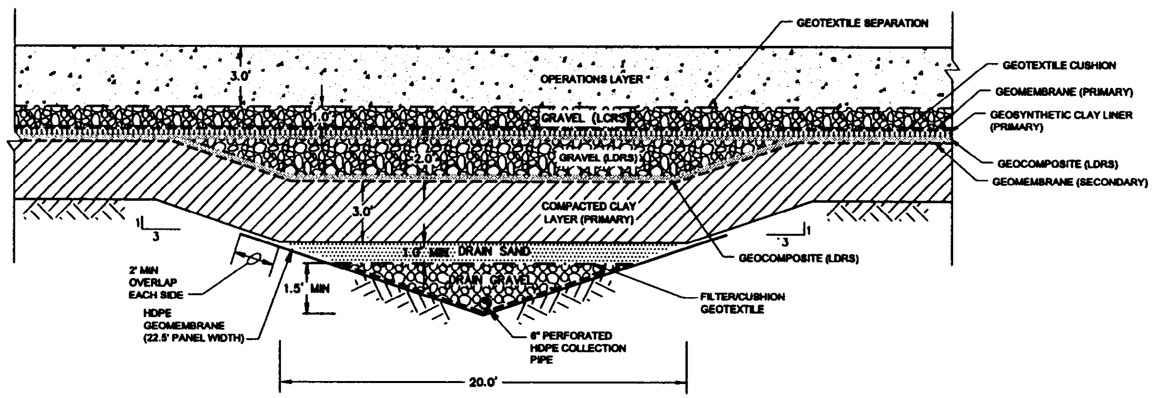


ICDF LDRS SUMP NORTH - SOUTH CROSS-SECTION

1" = 6'-0"



ICDF LDRS SUMP EAST - WEST CROSS-SECTION

1" = 6'-0"

FIGURE I-2
VADOSE ZONE MONITORING

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